

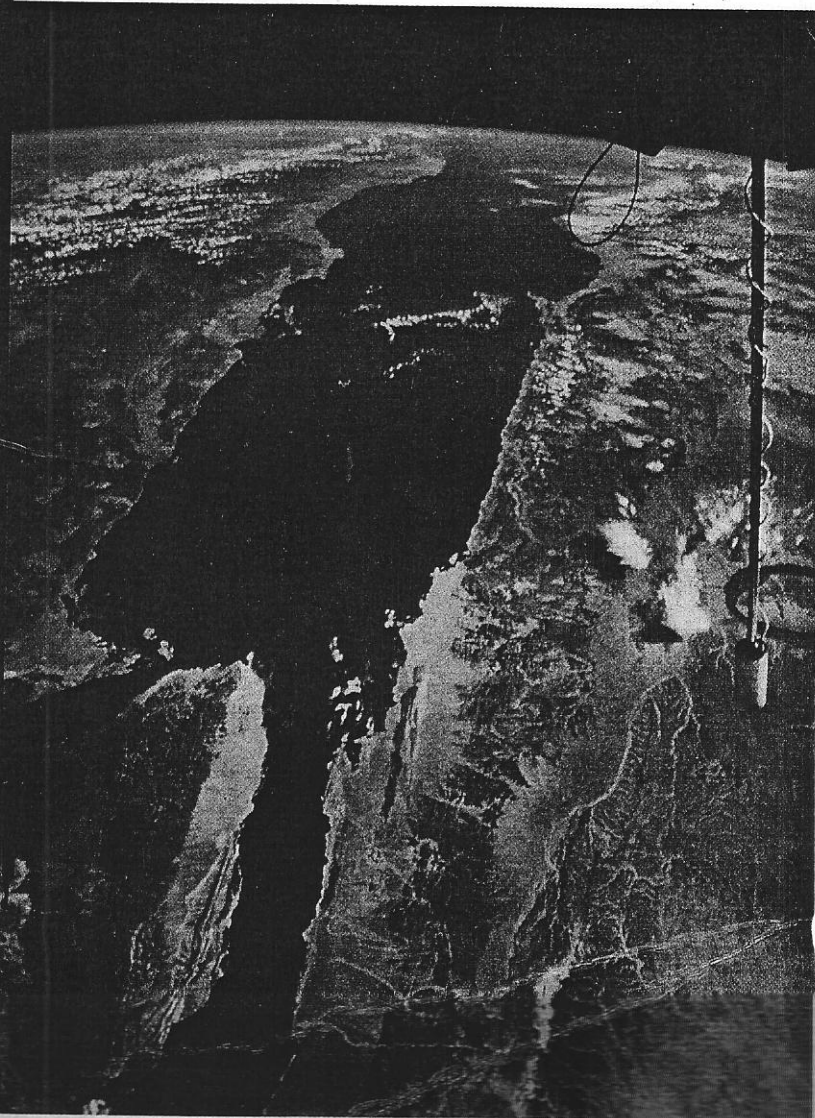
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SEDIMENTATION
OF THE RED SEA - GULF OF ADEN
RIFT SYSTEM**

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**PALEOKARST SURFACES IN THE NEOGENE
SUCCESSION OF WADI ESSEL - WADI SHARM
EL BAHARI AREA, EGYPTIAN RED SEA COAST;
AS INDICATION OF UPLIFTING AND EXPOSURE**

M.M. EL AREF

Geology Department, Faculty of Science,
Cairo University, Egypt

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Celestite, Red Sea.

Two different styles of paleokarst are recognized in the Neogene succession of the Wadi Essel-Wadi Sharm El Bahari area, Egyptian Red Sea coastal zone: 1) buried paleokarst surfaces of minor magnitudes, interrupting the Middle Miocene rocks. They represent short-lived exposure events during syn-rift uplifts, one of which hosts precipitated celestite deposits; 2) regional (exposed) paleokarst surface, representing long exposure related to post Late Miocene ?-Pliocene tectonic phase. Paleokarst surfaces are recognized on the basis of a variety of distinct features, the morphology of each surface and the associated solution processes and subaerial karst products, specially solution breccias and cave fills. These surfaces reflect the paleotopographic evolution of syn-rift sediments and the associated phases of sea-level fall. They are an essential guide for further exploration of related mineral resources.

INTRODUCTION

Surficial karstification of the Neogene carbonates and evaporites of the Red Sea coastal zone and related ore deposits were studied by previous workers (El Aref, 1981, 1984; El Aref and Amstutz, 1983; El Aref and Ahmed, 1986 and El Aref et al., 1985, 1986). Unfortunately, Red Sea karst features have been given little attention or completely repudiated in other recent studies, specially those concerned with the problem of rifting and sedimentation; e.g. El Haddad (1984); Jarrige et al. (1986); Bayer et al. (1988); Montenat et al. (1986b, 1988); Philobos and El Haddad (1983, 1984); Philobos et al. (1988, 1989); Purser and Hotzl (1988); Purser et al. (1987, 1990a); Roussel et al. (1986) and others. Furthermore, several exposed karst features and subaerial products were interpreted in some of these publications as normal submarine talus deposits and algal structures or attributed by Plaziat et al. (1988, 1990) and Purser et al. (1990a) to synsedimentary deformation processes of seismic activity during periods of earthquake instability.

Defined age	Different rock units applied by previous authors	Nomenclature used in the present work
Oligocene?-Early Miocene (Aquitainian, Montenat et al., 1986a)	Lower clastic Member of Gabal El Rusas Fm. (El Akkad and Dardir, 1966; NSSC, 1974) Proto-rift group A (Montenat et al., 1986a, 1988; Purser et al., 1990b)	Ranga Fm.
Middle Miocene, Langhian-Burdigalian (Montenat et al., 1986a; Roussel et al., 1986; Plaziat et al., 1990)	Upper carbonate Member of Gabal El Rusas Fm. (El Akkad and Dardir, 1966; NSSC, 1974). Group B (Montenat et al., 1986a; Purser et al., 1990b)	Um Mahara Fm
Middle-Late Miocene-(Montenat et al., 1986a)	Gypsum Fm. (El Akkad and Dardir, 1966) Group C (Montenat et al., 1986a; Purser et al., 1990b)	Abu Dabbab Fm
Late Miocene?-Early Pliocene (Hermina et al., 1989)	Oil tinted limestone (Beadnell, 1924, NSSC, 1974)	Um Gheig Fm.
Late Miocene?-Pliocene (Hermina et al., 1989)	Samh Fm. and the lower part of Gabir Fm. (El Akkad and Dardir (1966). Group D (Montenat et al., 1986a; Purser et al., 1990b)	Mersa Alam Fm
Pleistocene-Holocene	Undifferentiated coastal deposits and Wadi	alluvium

In order to clarify the relation between rifting history, sedimentation, subaerial karstification and related mineralization, the Neogene sequence of the area between Wadi Essel and Wadi Sharm El Bahari (Fig. 1) has been reinvestigated. The present work reveals three main episodes of emergence and karstification. The stratigraphy and facies evolution of the host Neogene succession in respect to the paleokarst surfaces are presented. Special attention has focused on the discrimination and description of each paleokarst surface, the related features and products. The results of these investigations are integrated in a schematic evolutionary model which indicates the drastic paleotopographic changes relating to relative sea-level fluctuations during Neogene rift history.

The sedimentary cover of this area consists of pre-rift Cretaceous clastics and carbonates followed unconformably by a series of syn-rift Neogene to Quaternary deposits (Fig. 1). These rocks are dissected by numerous major NW (Clysmic) and NE (Aqaba) faults which appear to be inherited from the basement structure, rejuvenated throughout the development of a series of horsts and grabens and juxtaposition of different stratigraphic units. A group of minor synclines and anticlines, trending ENE, NE and NNE, normal to the Red Sea coast and plunging towards the shoreline are also recorded. These structures affect Pliocene sediments (Fig. 1).

LITHOSTRATIGRAPHY AND FACIES EVOLUTION

Five representative sections were studied (Fig. 2). Based on the recent reviewed stratigraphic scheme of the Red Sea coastal zone, proposed by Hermina et al. (1989), the following syn-rift stratigraphic units are recognized and also correlated:

The Ranga Formation rests unconformably on either Precambrian rocks or tilted strata of pre-rift Cretaceous sediments and is unconformably overlain by the Um Mahara Formation. Maximum thickness of about 20 m was recorded in section 5 (Fig. 2). Northward, at sections 3 and 4 (Fig. 2), the thickness of this unit decreases, while further north, at sections 1 and 2 (Fig. 2), this unit is missing. It consists of repeated coarsening-upward continental sequences of sandy mudstones, gravelly sandstones and polymitic conglomerates. Philobos and El Haddad (1983), Jarrige et al. (1986) and Montenat et al. (1986a) showed that these proto-rift clastics accumulated in structural depressions, generally oriented N 020° (Aqaba-trend) and/or N 100-120° (Duwi trend) and resulted from early compressional strike-slip movement. A regional tectonic movement, related to a "mid clysmic" tectonic event (Grafunkel and Bartov, 1977) was responsible for the development of a series of horsts and grabens after the deposition of this unit (Roussel et al., 1986; Purser et al., 1990b).

The Um Mahara Formation, up to 35 m thick, comprises five distinct lithofacies which represent mixed clastic and carbonate sediments including reefal, clastic tidal-flat, beach, subtidal to intertidal and supratidal to intertidal

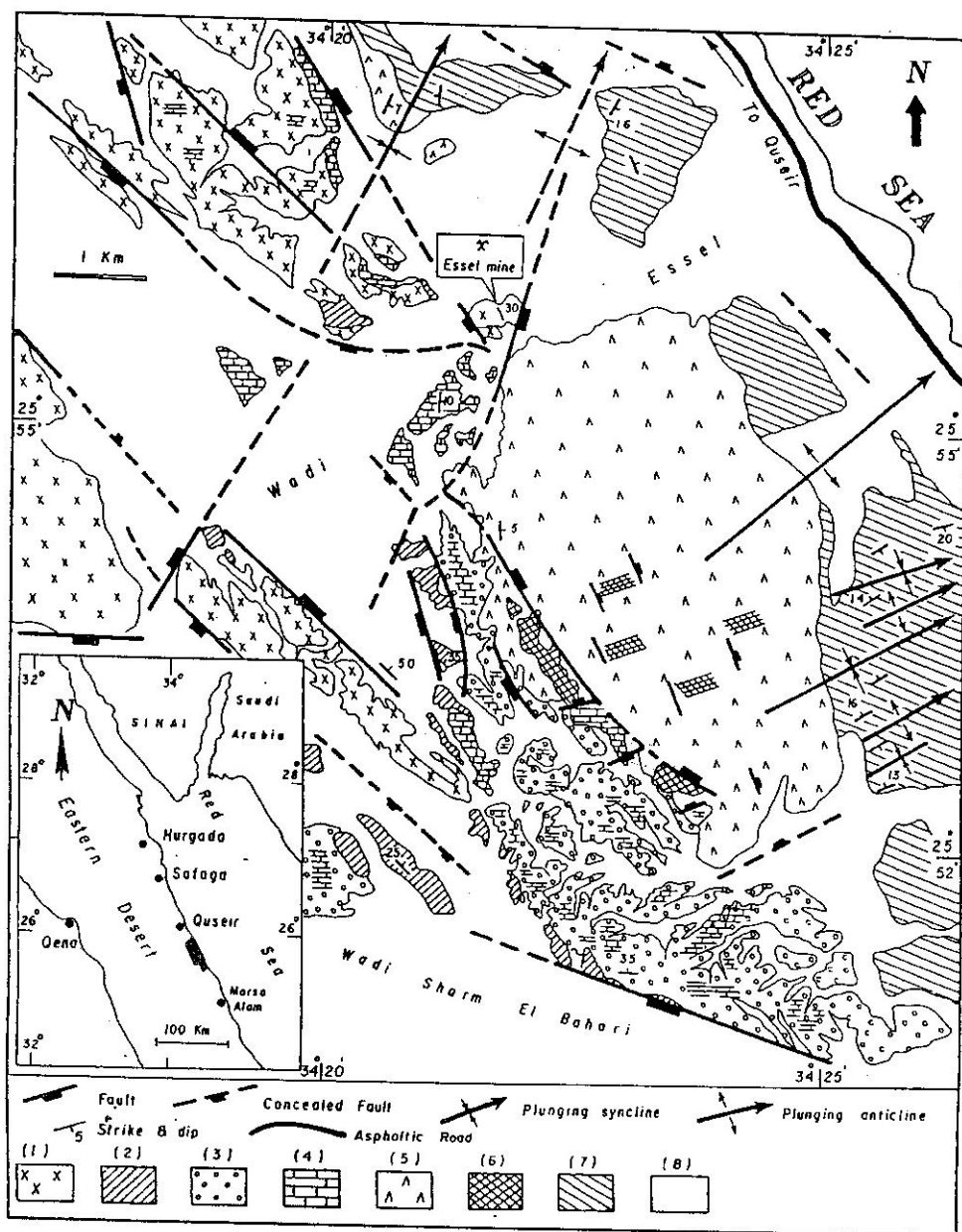
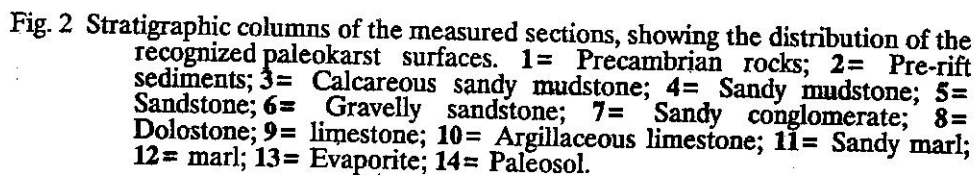


Fig. 1 Geological map of Wadi Essel-Wadi Sharm El Bahari area (modified after El Haddad, 1984).
 1= Precambrian igneous and metamorphic rocks; 2= Pre-rift sediments (Cretaceous); 3= Ranga Fm., 4= Um Mahara Fm., 5= Abu Dabbab Fm., 6= Um Gheig Fm., 7= Mersa Alam Fm., 8= Pleistocene-Holocene.



facies. These facies constitute a shallowing upward sequence with a general transition to supratidal-intertidal environment. In some places, this sequence continued into the evaporites of the overlying Abu Dabbab Formation. However, the lateral thickness and facies changes as well as the karstification and erosional contacts of certain facies indicate variable paleo-topographic and -geographic settings accompanied with intermittent transgressive and regressive events during their development.

The reefal facies occurs at the base of this formation at section 1 where it directly overlies the basement rocks and is separated from the overlying tidal-flat deposits by a paleokarst surface (k_1 , Fig. 2). It is composed of poorly bedded cavernous limestone, sandy in part, and rich in reef building corals and algae with several varieties of reef sheltered mollusks and lithofagus borings. The growth of this facies on, and along, the slopes of the basement rocks without traces of continental sediments indicates the presence of structural highs of Precambrian rocks during the early stage of Early Miocene marine ingression. The succeeded tidal-flat facies, 16 m thick, overlies the k_1 paleokarst surface or is directly deposited on Precambrian rocks. Its upper contact is erosive being marked by a paleosol, 6 m thick. It is composed of interbedded polymictic conglomerates, sandstones and mudstones showing lenticular and flaser bedding, graded bedding, ripple cross-lamination and desiccation cracks. At Essel mine (section 2, Fig. 2), this facies grades into a beach succession of cross-bedded mature sandstones intercalated with gravel and mudstone lenses locally rich in heavy mineral concentrates. These rocks include syndiagenetic galena in the form of stratiform to stratabound concretions, layers and laminae (El Aref and Amstutz, 1983). Southwards, at sections 3, 4 and 5 (Fig. 2), the tidal-flat and beach facies change into subtidal-intertidal facies, consisting mainly of calcareous mudstone intercalated with thin limestone bands and sandy conglomerate lenses. These rocks show abundant bioturbation and flat bedding. At section 5, this facies is truncated by 3 m thick paleosol.

Resting on the aforementioned facies and paleosols is a 6 to 10 m thick celestite bearing supratidal-intertidal facies, representing deposition in a nearshore restricted basin during a period of tectonic stability and constant sea level. This facies comprises alternated beds, 10 to 50 cm thick, of algal laminated and evaporitic limestones and thin massive calcareous mudstones, dolomitic in part. This succession is topped by a paleokarst surface (k_2 , Fig. 2), well represented at sections 2 and 3 where this surface is buried under either bedded dolostones of the Um Gheig Formation or mudstones and evaporites of the Abu Dabbab Formation. At section 5, nonkarstified rocks of this facies are directly followed by the Abu Dabbab Evaporites. At sections 1 and 4, the karstified rocks of this facies remained exposed during the deposition of the succeeded Abu Dabbab and Um Gheig formations and have clearly undergone later intensive weathering during a third karst event (post-Um Gheig uplift karst, k_3 , Fig. 2).

The primary lamination of this bedded facies is formed of 1 mm-3 cm

couplets of alternating brownish stromatolitic laminae and celestite-rich laminae, giving rise to a characteristic syndimentary rhythmic pattern (Fig. 3a), which corresponds to the diagenetic crystallization rhythmic texture of Fontbote and Amstutz (1980, 1982) and Brodtkorb et al. (1989). Occasionally, this type of lamination forms connected or disconnected domes, up to 40 cm high, often encountered within evenly laminated beds. Laminoid fenestrae, desiccation cracks, tepee and enterolithic textures are frequently observed within evenly laminated beds (Fig. 3b). Lenticular cavities and nodules after dissolution of gypsum, sometimes replaced by celestite and/or calcite, also occur. Progressive desiccation forms aligned polygonal plates (Fig. 3b). The other striking feature of this facies is the abundant distribution of other penecontemporaneous features such as convolute lamination and slump folds and faults (Fig. 3a). Slump movements may affect several beds and form small scale recumbent and tight overturned folds, up to 40 cm (Fig. 5a), most of them are generally arranged parallel to the strike of the host laminated rocks. Some isolated wedge-shaped bodies of highly folded and faulted laminae are enclosed within undeformed beds. These bodies, 20 cm to 2 m in diameter, are usually flat-based and have a convex upper surface. The laminae within these bodies become highly crumpled, overfolded and overthrust, consequently until they mash together in a disharmonic pattern. The style and magnitude of these features suggest syndimentary deformation during subaqueous slumping along original inclination surfaces. They have been interpreted as "seismic deformation structures" by Plaziat et al. (1990).

The celestite of the stratiform celestite laminae (assigned here as generation I celestite) exhibits the following microscopic forms: 1) equidimensional fine-grained crystal aggregates or polygonal mosaic with individual crystal of up to 100 μm wide, in diameter, forming continuous laminae rich in algal filaments, micritic peloids, patches of micrite and remains of gypsum; 2) preferably oriented lenticular crystals, up to 0.5 mm long and 300 μm wide, distributed within micrite matrix and arranged parallel to the bedding. They often corrode the surrounding matrix and include calcite and gypsum inclusions; 3) stratiform arrangement of rosettes or spherulites of flat lense-like crystals or fibroradiating aggregates, up to 1 mm in diameter, surrounded by a micrite matrix rich in algal filaments. Continuous growth and coalescence of such forms may constitute single laminae of convex-concave upper and lower surfaces, which displace the surrounding algal-concave upper and lower surfaces, which displace the surrounding algal-dominated matrix and the former oriented celestite and gypsum crystals. Relics of micrite are often found within celestite spherulites; 4) individual crystals of swallow-tail twins growing perpendicular to the bedding within micritic matrix; 5) prismatic crystals, up to 600 μm in length and 200 μm in width, filling primary fenestral cavities and pore spaces and 6) replacement of former displacive gypsum nodules. The congruent relation between the celestite laminae and the intercalated stromatolitic laminae, their rhythmic character and syndimentary deformational structures as well as the microscopic diagenetic fabrics, all indicate that this generation of celestite was formed syngenetically in the host supratidal-intertidal facies, through replacement of precursor minerals (gypsum and/or Sr-rich carbonates) and sequential crystallization,

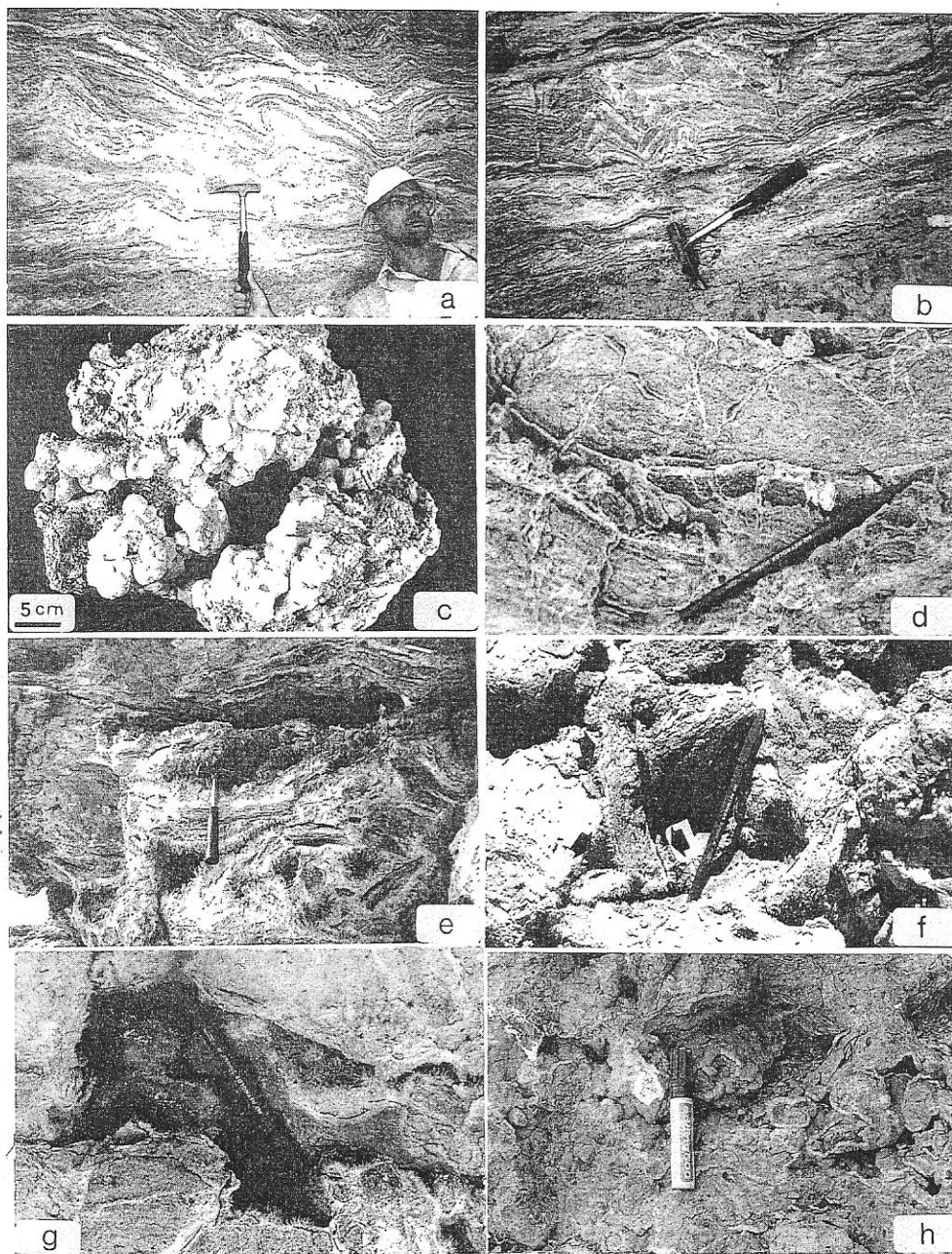


Fig. 3 a. Rhythmic pattern, convolution and folding of the celestite bearing facies. b. Tepee structure and desiccation cracks in the celestite-bearing facies. c. Solution cavity within coralline limestone lined by coarse-grained calcite (white), k_1 karst. d. Solution-enlarged bedding feature, joints, desiccation cracks and caverns, with reprecipitated calcite and celestite, k_2 karst. e. Joint and bedding plane-controlled cavities with speleothems of calcite and celestite, k_2 karst. f. Collapse breccia cemented by large calcite and celestite crystals (arrow), k_2 karst surface. g. Solution cavity coated by calcite and celestite, k_2 karst. h. Close-up of nodular calcrete, k_3 karst surface.

recrystallization and deformation during diagenesis. The paleoenvironment and syngenetic fabrics of this celestite type can be correlated with the well-known syngenetic celestite deposits elsewhere, e.g. Permian of Greenland (Scholle et al., 1990); Triassic of Bristol area, England (Anonymous, 1974; Nickless et al., 1975, 1976); Jurassic Hammelete West deposit, Germany (Muller, 1962; Brodkorb et al., 1982), Late Miocene celestite of Granada basin, Spain (Martin et al., 1984) and the celestite of Wenlock Oslo Region, Norway (Olausson, 1981).

A major phase of faulting occurred soon after lithification of the celestite-bearing facies and rejuvenated during and after the deposition of the succeeding evaporites. This phase, which most likely related to the regional post-Group B and pre-Group C tectonic stage of Montenat et al. (1988); Plaziat et al. (1990) and Purser et al. (1990b), resulted in the development of westwardly upthrown blocks of the Um Mahara Formation and migration of the shoreline toward the east, where restricted basins were created and deposition of the Abu Dabbab Evaporites took place. The exposed uplifted blocks of the Um Mahara Formation were subjected to subaerial karstification (k_2 karst event), during which solution processes and formation of young generation of celestite (generation II karst related celestite) have evolved. Some karstified blocks of this unit were subsequently downfaulted and buried either under the Abu Dabbab Evaporites as in section 3 or the Um Gheig Formation as in section 2.

Abu Dabbab Formation attains up to 50 m in thickness and consists mainly of bedded and laminated gypsum and anhydrite with mudstone and dolostone intercalations.

Um Gheig Formation directly overlies the Abu Dabbab Evaporites or is unconformably deposited on the karstified rocks of the Um Mahara Formation (sections 5 and 2, respectively). It is up to 30 m thick and consists of a complex of interbedded limestones and dolostones of supratidal-inertial origin. The original textures of these rocks are highly obliterated due to intensive dolomitization and subaerial karstification. The following lithofacies predominate: algal laminated lime-mudstone, sandy in part; algal, laminated dolostone, green mudstone, calcitic dolostone and dedolomite. Fine, even, or convoluted lamination, cryptalgal laminites, birdseye structure, displacive gypsum crystals and nodules and desiccation cracks are common. Local concentrations of mollusks and coralline algal fragments are also observed in some beds. Black bituminous materials locally fill pores. These rocks form a conspicuous duricrusted karst whose cone-hills constitute an integral part of the exposed k_3 karst surface.

Post-Um Gheig faulting resulted in the emergence of the Abu Dabbab and the Um Gheig formations, uplift of the rift shoulders and eastward migration of the shoreline, where the rocks of the Mersa Alam Formation were deposited.

The Mersa Alam Formation occupies a narrow zone situated close to

the present coast and, within its lower part, includes fluvio-marine marls, shales and conglomerates followed by poorly bedded marine bioclastic and coralline limestones. These rocks lie in front of the seaward-tilted Abu Dabbab Evaporites and are never recorded above the Um Gheig Formation.

PALEOKARST SURFACES

1. Intra-Um Mahara k_1 Fossilized Surface

A representative cross-section of this surface is shown in figure 4A which illustrates features observed from outcrops in section 1. This surface sharply truncates the uppermost part of the reefal limestone of the Um Mahara Formation and is directly overlain by siliciclastic tidal-flat deposits. It consists of a series of bowl and funnel-shaped pits and sharp-crested solution sculptures and basins (karren), interrupted by domal and peaked projections. These surface solution forms are mostly filled with siliciclastic sediments of the overlying facies and lithoclasts and bioclastic debris derived from the karstified carbonates. Some of these carbonate clasts are mixed with the siliciclastic sediments. The surface dissolution features show obvious connection, through widened joints and channels, with subsurface cavities which may penetrate several meters down from this surface (Figs. 4B, C). Around the solution channels and cavities enlarged solution joints form a complex network pattern enclosing highly brecciated rocks. The enclosed rocks are dominated by vuggy pores. Below the paleosurface, cavities and channels are partially or completely filled with angular to subangular collapse breccias which are gradually dislocated and displaced from the walls and roofs of these solution forms. Large clasts often show in situ brecciation, with decreasing-upwards particle size. Clasts are either matrix- or fragment-supported or partially to completely coated by coarsely crystalline rhombic calcite. The solution channels, cavities and joints are often lined by laminated calcite (speleothems), individual laminae thickening towards their central parts. These speleothems have variable thicknesses ranging from few millimeters to several centimeters. They may constitute a single layer of equant calcite crystal aggregates with individual crystal size up to 1 cm (Fig. 3c) or repetitions of thin layers of fibrous radial and coarser bladed calcite crystals showing optical continuity and idiomorphic terminations towards pore spaces. Other speleothem coatings show palisadic calcite composed of large columnar crystals forming centimeter-thick layers intercalated within thin laminations of microgranular calcite. The residual spaces are either empty or filled with orthosparitic calcite. Geopetal internal sediments are also preferentially distributed within the solution features (Figs. 4B, C). They consist of organic-rich material or silty lime mud, with or without crystal silt of calcite, or mostly of speleothems. These materials occur either as partial filling on floors of cavities, or as matrix and cement between breccia fragments, most commonly in the lower levels of the cavities and channels.

2. Post-Um Mahara Paleokarst Surface (k_2 Karst Hosted Celestite)

This surface is generally of cusped form being pitted and rubbly in some places. Near-surface solution joints and channels are often connected

Fig(4) Representative sketches showing the fossilized K_1 paleokarst erosion surface (A) and details of the associated solution features and karst products (B & C).

1= Karstified reefal limestone.

2= Conglomerate.

3= Karst erosion surface. 4= Karren

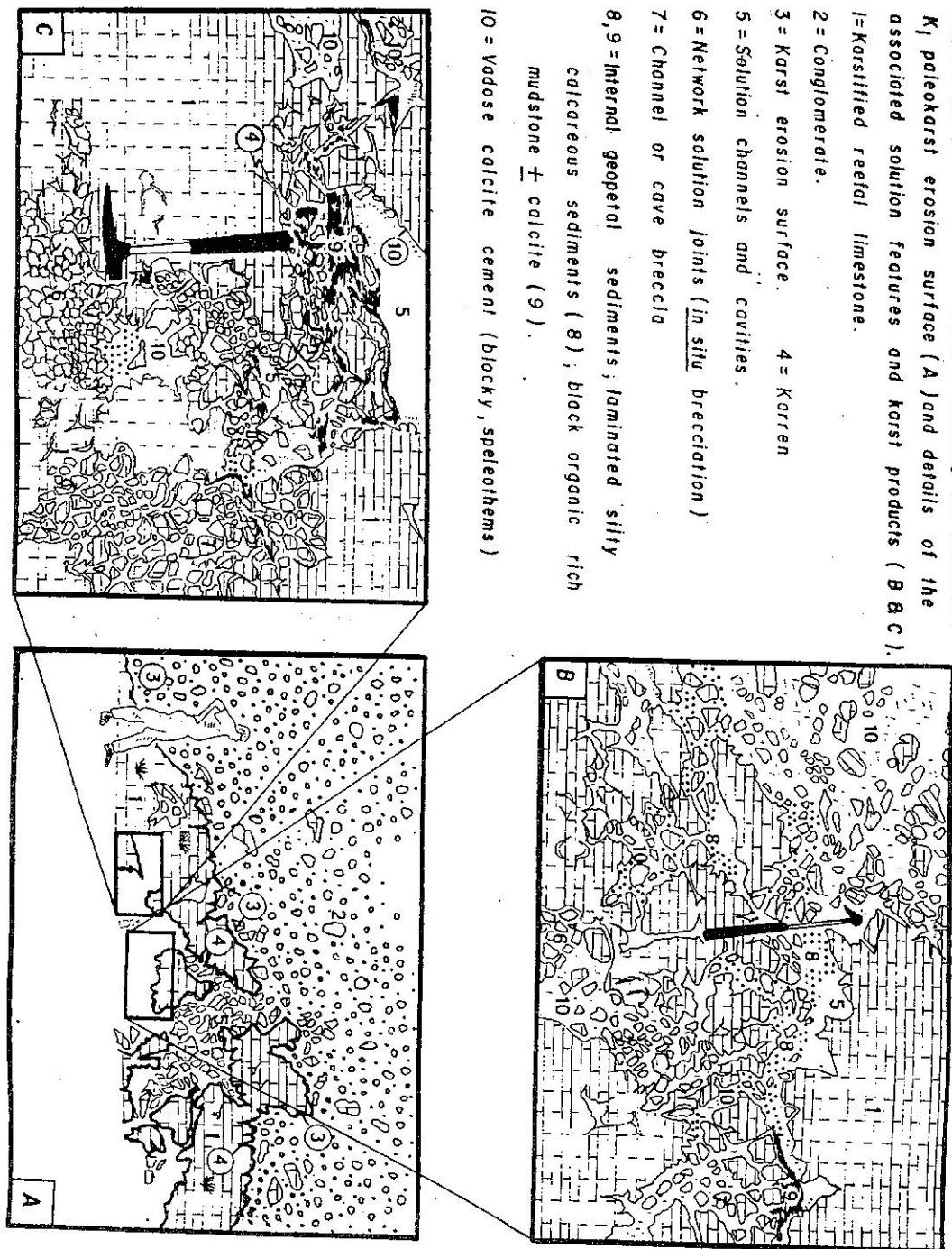
5= Solution channels and cavities.

6= Network solution joints (in situ brecciation)

7= Channel or cave breccia

8,9= Internal geopetal sediments; laminated silty calcareous sediments (8); black organic rich mudstone + calcite (9).

10= Vadose calcite cement (blocky, speleothems)



with subsurface solution cavities (Fig. 5A). The solution features show successive stages of widening as a result of dissolution under vadose or transitional vadose-phreatic conditions possibly during progressive lowering of the paleowater-table. Karst effects may extend down to the contact between the host karstified celestite-bearing facies and the underlying subtidal-intertidal calcareous mudstone. This may indicate the amplitude of emergence during this karst event.

Bedding and fault planes, cleavage of folds, joints, fractures and desiccation cracks are the fundamental lines of weakness along which progressive dissolution and widening took place (Figs. 3d; 5 and 6). The solution cavities are often enlarged and partially to completely filled with solution breccia and karst precipitates (Figs. 5B, C). Many cavities were developed in close association with highly folded beds ("Seismite" structures of Plaziat et al., 1990) leaving behind blocks of tightly folded laminae or beds and/or in situ solution breccia fragments which may still preserve the original folding character of the parent rocks (Fig. 5B). Small scale solution forms tend to initiate along desiccation cracks of different levels, giving rise to V-shaped openings, up to 1 cm wide and 4 cm long (Figs. 3d and 6A). Progressive widening develops keyhole-like cavities which may extend downward for 80 cm. Continuous widening along bedding planes, joints and cracks resulted in the formation of connected meandering passages and an anastomosing network of tubes or irregular solution cavities (Fig. 6B). Reticulate network of joint-controlled passages are frequently visible along the roofs, walls and floors of large-scale cavities (Figs. 6C-F). Bedding oriented tabular passages, basally incised by V-shaped enlarged joints are frequently observed (Fig. 3e). Solution pockets, enlarged half tubes and small notches occur in the roofs of some large-scale cavities which often follow one or two major joint system (Fig. 3g). They may extend upwards for a distance of tens of centimeters and usually terminate, through a network solution pattern, in tight joints or fractures that are not solution widened and evidently guided the expansion of the associated large scale cavities. Solution undercutting of channel and cave walls are common. Cave walls and ceilings also exhibit small contiguous dish-shaped depressions (scallop or flutes) which do not show obvious connection with cross-cutting fractures and indicate sculpturing under phreatic to vadose-phreatic condition.

Microscopic solution features include: 1) enlarged fabric selective pores result in a widening of original fenestral and stromatactis-like cavities and dissolution of sulphate rosettes, nodules or laminae; 2) nonselective dissolution voids resulted from etching of the carbonate cement and matrix; 3) intragranular solution pores and vugs within the breccia fragments and 4) mottling and micritization along widened solution features and surfaces of solution-breccia fragments. The original micrite and microspar are commonly recrystallized into neomorphic sparry calcite, eventually into the formation of clotted fabric, consisting of patches of micrite and peloids entirely surrounded by neomorphic spar. The syndimentary gypsum and celestite (generation I celestite) are commonly replaced by sparry calcite.

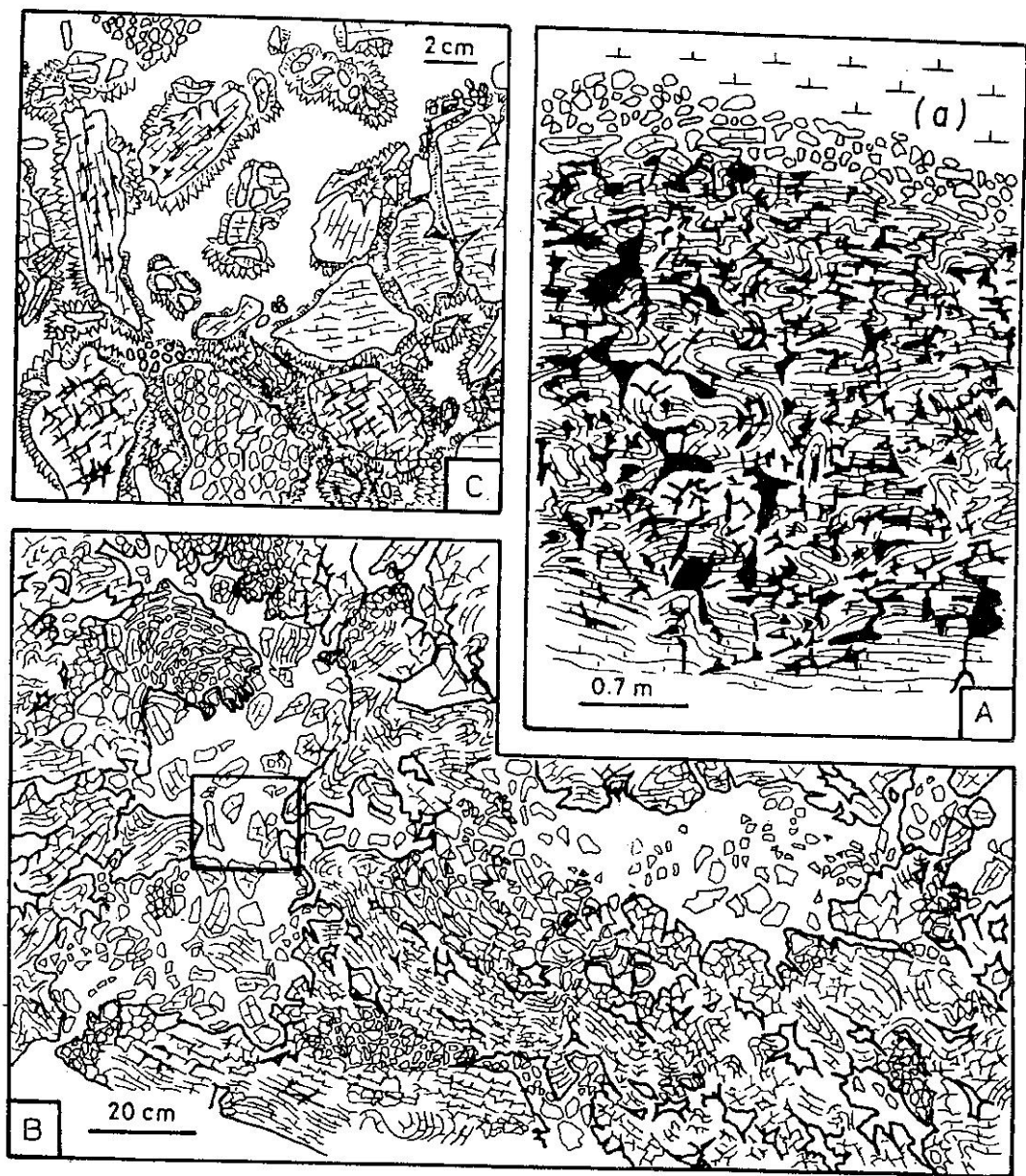


Fig. 5 A. Representative cross-section of the k_2 karst surface beneath Abu Dabbab Fm. (a). Notice the rubby upper portion and the distribution of solution passages and cavities (in black) within the folded celestite bearing rocks. B. Solution cavities and channel with intrakarstic precipitates. C. Enlargement of the channel-fill sediments squared in figure B, showing in situ brecciation of large clasts and encrustation by calcite and celestite speleothems.

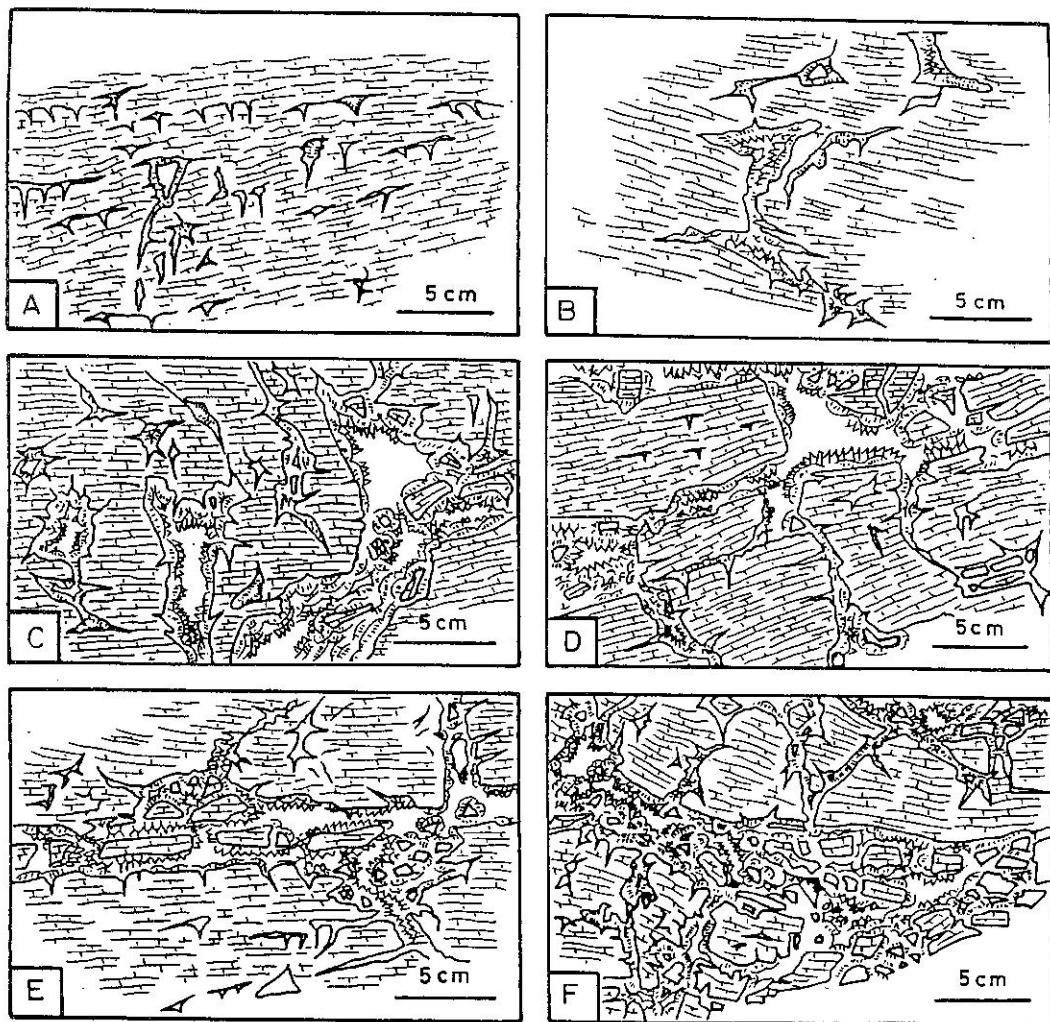


Fig. 6 Progressive dissolution along desiccation cracks (A) , Fractures (B,C) and bedding planes (D-F) with intrakarstic precipitates (collapse breccia, and speleothems), k_2 karst.

Intrakarstic deposits include solution breccia, speleothems of calcite and celestite (generation II celestite) and internal geopetal sediments (Figs. 3d-g). The solution breccia fragments are distinguished by their intimate association with solution forms, their rounded and corroded clasts and their pervasive coarse-grained calcite cementation (Fig. 3f). They exhibit several forms, including: 1) crackle breccia with no or little displacement but with obvious transition to boxwork pattern of self-supporting framework, ultimately into completely separated and slightly dislocated fragments, commonly distributed along channel and cave walls, floors and roofs; 2) discordant cave and channel collapse breccia of a sinuous or linear pattern; 3) concordant breccia bodies or stratal dissolution collapse showing crude orientation parallel to the enclosing, widened, bedding planes (Figs. 3d and 6 E,F); 4) dome-shaped columns or chimney-like breccia bodies generated by in situ fragmentation along tensional joints and network fractures mainly in fold hinges (Fig. 5B) and 5) collapse breccia fragments of variable size and shape derived from the cave and channel roofs and walls, sometimes linked by calcite cement along the walls of some cavities. These solution-breccia fragments range from fragments identical lithologically with that of the wall and roof rock, or varied lithologies specially within large cavities that cut across several beds. Precipitation of coarse-grained calcite and celestite (generation II celestite) together with internal geopetal sediments caused partial to complete filling of the intergranular spaces between the solution-breccia fragments and the megascopic and microscopic solution features. The karst-related calcite and celestite comprise stalactites and stalagmites of variable scales (Figs. 3 e-g, 5 and 6). These speleothems are composed of a succession of radiaxial fibrous mosaic, bladed and wedge-shaped crystals growing perpendicular to the roofs and floors of the solution features. These crystals often show increase in size and pyramidal or comb structure against internal geopetal sediments and/or coarse-grained equant calcite. Crusts and films of calcite and celestite flowstone are commonly deposited around collapse breccia fragments (Fig. 3f) or on cavity roofs and floors. Asymmetric fringe calcite and celestite growing preferentially downwards into open spaces are common. Nodules of calcite and celestite frequently occur on the floors of some large cavities. They consist of dog-tooth crystals, some of which show eccentric radial arrangement and include relics of highly disintegrated rock fragments. Calcified algal filaments similar to the calcite algal tufa of Irion and Muller (1968) and alveolar texture to Esteban (1974) are often observed along the outer margins of stalactites and stalagmites or the internal walls of some solution features. Some megascopic and microscopic solution features are floored with geopetal precipitates consisting of a mixture of silt-sized calcite and celestite particles and red stained calcareous mud lacking other coarser impurities. These deposits postdate the idiomorphic terminations of the calcite and celestite speleothems and predate later blocky and equant calcite crystals. The karst-related celestite forms large tabular crystals of idiomorphic ends towards pore spaces, up to 15 cm in their maximum dimension. They clearly replace the closely associated infilling calcite and often predate the geopetal sediments and late blocky calcite cement.

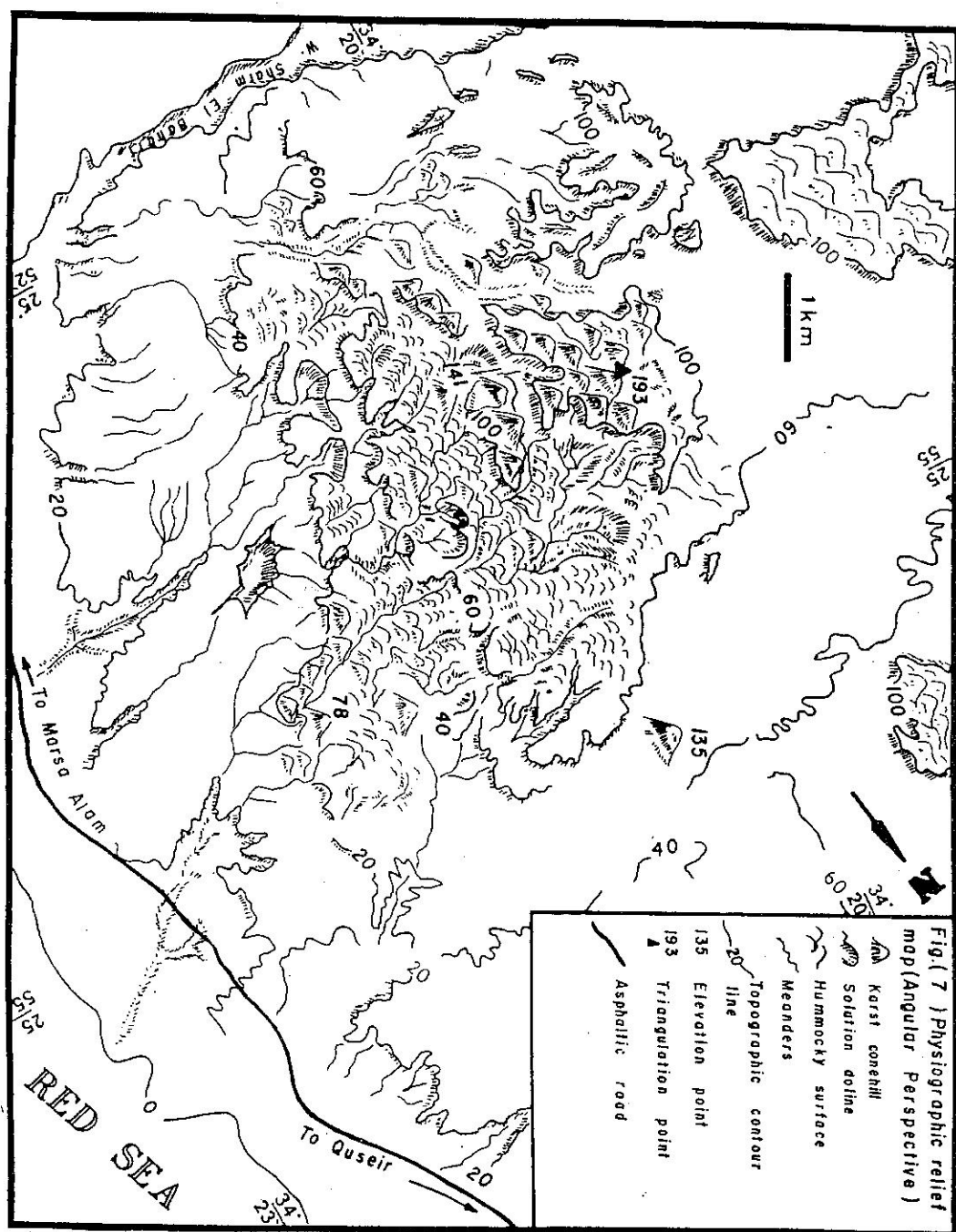
The breccia and fold structures described above have been

interpreted by Plaziat et al. (1990) as being the result of Miocene earthquakes. These authors suggest that folding and brecciation are genetically related. Furthermore, Plaziat et al. (op. cit.) did not observe a karst surface above these breccias, nor did they recognize the evolution of the karst-related dissolution features and brecciation or vadose diagenetic phenomena.

3. K₂ Exposed Paleokarst Surface

This surface is responsible for the configuration of the present day coastal zone topography and cuts across the uplifted Neogene units (Fig. 7). It shows a spectacular karst features having a general topographic gradient from the west to the shoreline which can be regarded as due partly to seaward tilting and step faulting together with westward backwearing. Paleoclimate, including seasonal rainfall, runoff, subsequent water-table lowering, evaporation and pedogenesis, structure, lithology of the country rocks and time controlled the evolution of these karst features. The exposed karstified rocks of this surface comprise the upper zone of a deep weathering profile which corresponds to the telogenetic zone of Choquette and Pray (1970) and the upper vadose zone of the ideal karst profile of Esteban and Klappa (1983) and Philip et al. (1991). This zone is composed of an upper surficial duricrust (calcrete with terra-rossa or gypcrete) capping the highly subdued carbonates or evaporites, which are dominated by vadose features. The depth of this zone ranges widely, depending on the base levels. On the high-standing karst topography towards the west, it attains 100 m, but in the areas of low relief near the shoreline, it is only few meters thick. Wadi Essel and Wadi Sharm El Bahari run across this surface and slope gently from west to east, their courses being inherited from the inland basement outcrops. The high-standing karst landforms represent the water divide of the adjacent lowlands and constitute retreated plateau remnants, flat-topped tablelands and ridges, often duricrusted and surrounded by structurally controlled scarps, up to 100 high. These scarps are highly embayed and based by large solution depressions as a result of lateral corrosion of stream floods and sideway recession. The tops of the plateau remnants are characterized by the abundant distribution of NE aligned symmetrical karst cone-hills. They have a constant hillslope angle of about 40° and their summits stand at a generally 180-193m a.s.l. Other isolated cone-hills at lower levels are frequently distributed along the main scarps and within wide tributaries but with general seaward decrease in their heights and diameters. The fault block of Essel mine exhibits a characteristic isolated karst cone-hill, that remained elevated during continuous deepening and widening of Wadi Essel. These karst cone-hills consist mainly of highly karstified rocks of the Um Gheig Formation. The hills are considerably mantled by calcrete duricrust, cementing breccia fragments (Fig. 3h). Calcrete shows characteristic orogano-sedimentary structures such as rhizoliths, calcified plant remains, algal filaments and lichen stromatolites and include remains of terra-rossa. Other mineralogical and isotopic characteristics of this duricrust appear in the works of El Aref et al. (1985) and Aissaoui (1985).

This high-lying duricrust is a good indication of subaerial pedogenic processes affecting an old erosion level above a paleowater-table. The karst hills are also dominated by solution cavities and channels of different



diameters and shapes, filled with collapse breccia fragments and conspicuous cave cements such as flowstone, isopachous cement rims, cave pearls and colloform crusts (Figs. 8a-c). This cave system extends down to the Abu Dabbab Evaporites (Fig. 8d) or the buried k_2 karst surface. Rejuvenation of the buried k_2 karst reopened cavities which host collapse fragments derived both from the karstified celestite bearing rocks and the overlying Um Gheig dolostones (Fig. 8b). Dedolomitization of the dolostone country rocks is obviously associated with the karstification of these rocks. As a result of sideways recession of the hillside slopes during subsequent fluvial periods and continuous lowering of the water-table (mature stage of karstification), etching and stripping of the high-lying duricrust took place. These processes led to gradual reduction of the hill diameters and heights consequently into the development of rugged outcrops covered by heterolithic rubble breccia and talus deposits cemented by younger generation of calcrete crusts. The surficial rubble breccia, in some places, tend to be transitional into deeper vadose solution features or may undergo further brecciation and transportation from higher to lower levels (Figs. 8 e,f). The tops of the flat-topped tablelands and ridges, up to 100 m a.s.l., are made up of intensively karstified rocks of the celestite bearing facies of the Um Mahara Formation which often show transition into subaerial calcrete-cemented rubble breccia and talus deposits. Progressive slope and scarp retreat led to the gradual decay of the relatively high-standing duricrusted interfluvies and formation of tower karst landform. Eastward, the exposed Abu Dabbab Evaporites form a seaward sloping, rugged and stepped surface, highly traversed by drainage lines of dendritic to subdendritic patterns, which slope gently towards the sea. The main courses of this drainage pattern are inherited from the higher duricrusted upland masses. The exposed evaporites develop characteristic karst cone-hills and small scale hummocks of different elevations surrounded by solution corridors that are often bottomed by solution sinks and karren features and run, through meander streams, into large-scale closed or opened dolines, up to 800 m in diameter (Fig. 7). These dolines are common downstream. They gathered surface drainage and served as funnels that channeled the surface waters underground or toward the sea. The mode of occurrence and distribution of these solution dolines led to the assumption that they were formed by surface water solution, at the time when much surface water accumulated and the gradient was not steep enough to allow fast surface runoff. The sidewalls of the dolines, small scale sinks and karren and the hillside slopes of evaporite cone-hills show evidence of brecciation, undermining and collapsing and are often covered by 20 cm to 2 m thick crust of alabastrine gypsum (gypcrete), (Figs. 8 g,h).

The development of the solution dolines and the associated duricrust along different levels and their continuous enlargement point to the lowering of the paleowater-table and helped in the headward retreat of the escarpments and, consequently, the general westward backwearing of the relief of this karst surface. It is therefore likely that the above described karst features of this k_2 surface were all formed during a single period of exposure and under sequential karst processes, but at different levels, guided mainly by differences in elevation above karst base-level, fluctuations in the

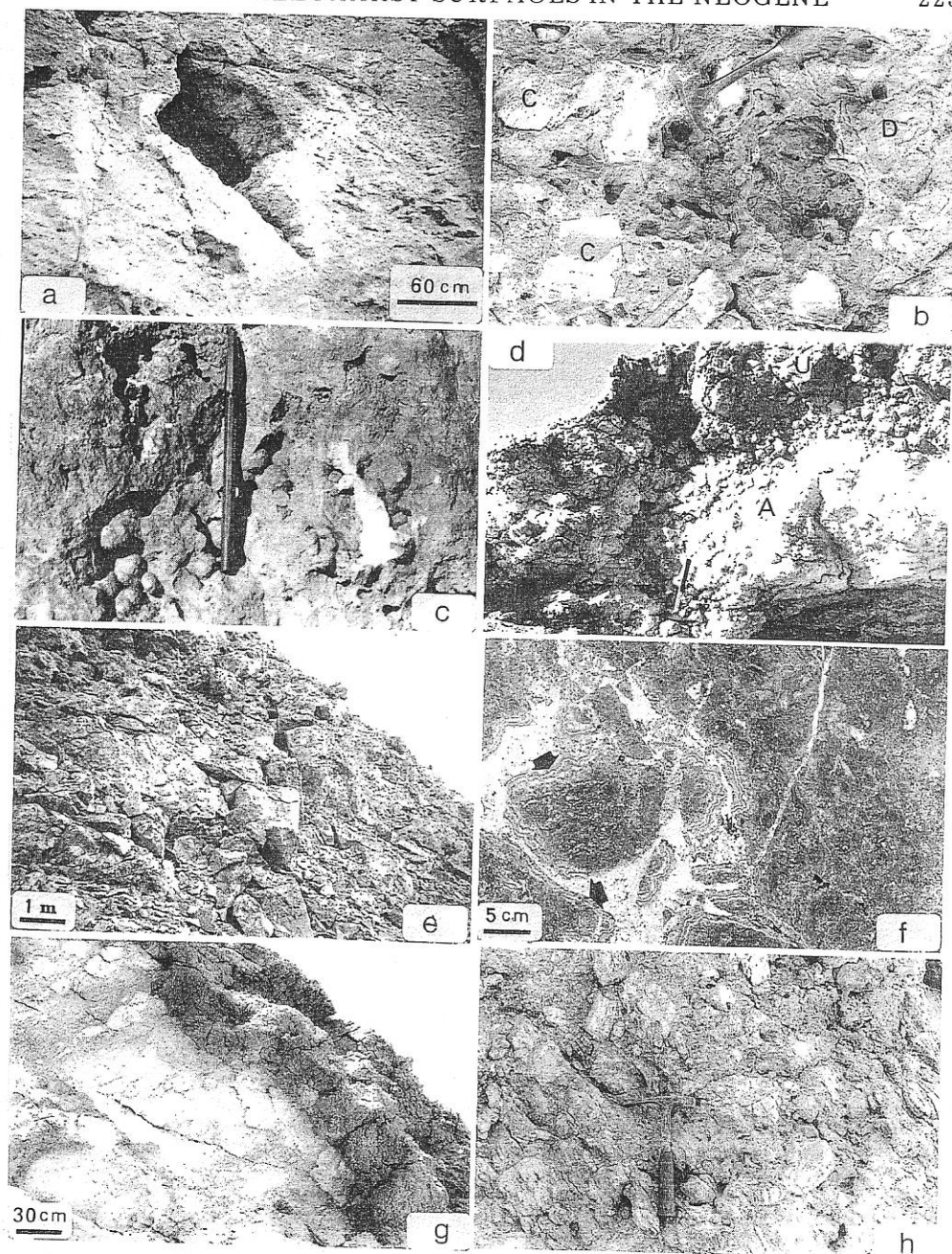


Fig. 8 a. Solution cavity within the calcitized dolostones of Um Gheig Fm., k_3 karst. b. Collapse breccia with heterolithic breccia fragments (C= celestite bearing rocks of Um Mahara Fm., D= calcitized dolostone of Um Gheig Fm.), cemented by crustified calcite, k_3 karst. c. Close-up of cave pearls, k_3 karst. d. Solution breccia and channel-fill along the contact between Abu Dabbab Evaporites (A) and Um Gheig dolostones (U), k_3 karst. e. Subaerial talus deposits along the hillside slope of karst cone of k_3 karst. The rock fragments consists of calcitized dolostone and calcrete. f. Calcrete and calcitized dolomite fragments cemented by younger generation of calcite crust (arrows), k_3 karst. g. Subaerial crust of alabastrine gypsum (grey) along the wall of solution doline, k_3 karst. h. Matrix-supported solution breccia of evaporites with secondary alabastrine gypsum and blocky calcite cement, k_3 surface.

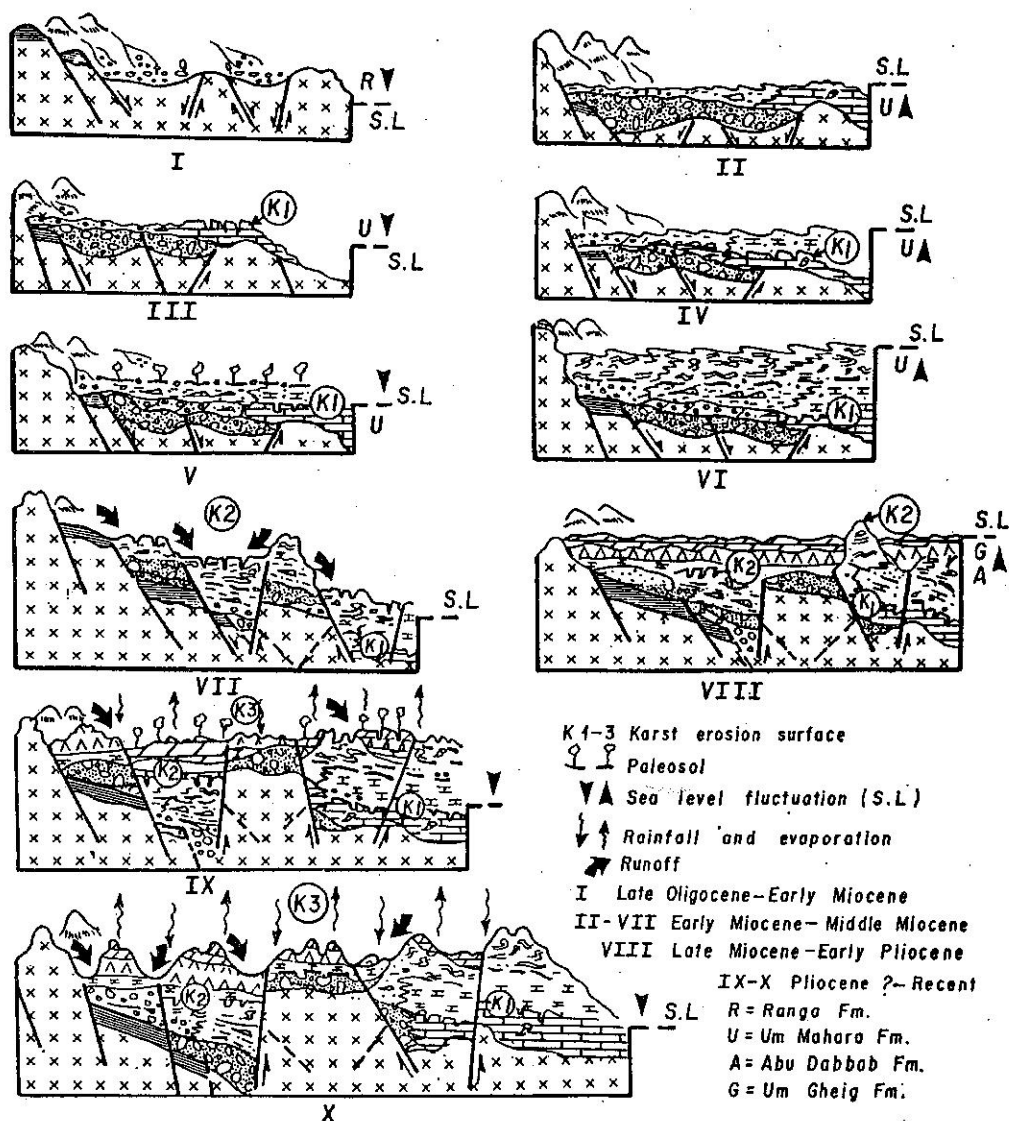


Fig. 9 Suggested stages of syn-rift sedimentation, emergence and paleokarstification (not to scale).

I = Block faulting, high relief, rapid erosion, fluvial deposition of fanglomerates, local soil formation.

II = Sea transgression, reef build up on high blocks, tidal-flat and clastic beach deposits of lowlands.

III = Uplift, sea regression, k_1 karstification.

IV = Sea transgression, tidal-flat and beach deposits, fossilization of k_1 surface.

V = Sea regression, erosion and soil formation.

VI = Sea transgression, local reef building, lagoonal to supratidal deposits, biogenic and syndimentary deformation.

VII = Block faulting, sea regression, juxtaposition of different stratigraphic units, k_2 karstification.

VIII = Sea transgression, deposition of evaporites and carbonates on different rock units, fossilization of k_2 surface.

IX = Block faulting, sea regression, k_3 karstification, duricrust formation.

X = Continuous karstification, incision of Wadis, stripping of duricrust, slope retreat, talus accumulation.

paleoclimatic conditions (wet-arid seasons) and continuous lowering of paleowater-table. These karst processes appear to have begun soon after the post-Um Gheig faulting phase and the related relative sea-level fall, reaching their mature stage during the Plio-Pleistocene pluvial periods, with karst rejuvenation during the Quaternary runoff regimes.

CONCLUSIONS

1. Three main episodes of emergence and karstification, indicating stratigraphic breaks, are identified in the Neogene succession of the Wadi Essel-Wadi Sharm El Bahari area. The first karst surface is a minor break outcropping only locally and indicates a short-lived exposure event with relative sea-level fall. The second karst event is related to post Um Mahara-pre Abu Dabbab rift faulting, and lowering of sea-level. The related karst features host considerable amounts of celestite. The third event is a major break and coincides with the regional post-Um Gheig tectonic event and relative lowering of sea-level. The related karst surface has been generated during a prolonged period of exposure under fluctuating paleoclimatic conditions and soil cover. The Pb-Zn sulphides and barite of Um Gheig, Wizr, Abu Ghorban, Gabal El Rusas and Ranga are hosted in karst features which belong to this third karst event (El Aref, 1981, 1984; El Aref and Amstutz, 1983; El Aref and Ahmed, 1986 and El Aref et al., 1986).
2. A schematic model (Fig. 9) illustrates the paleotopographic evolution and karstification of the studied syn-rift sediments.
3. The precipitation and enrichment of celestite in the second karst surface gives further support to the importance of the Red Sea karst features as essential places for accumulation of mineral deposits. Thus, regional investigation of the buried or exposed paleokarst features may be useful for further exploration.
4. The regional significance of these karst episodes throughout the Red Sea coast should be proven by careful documentation of correlative geologic features and unconformities. This may provide a more comprehensive picture of the Neogene stratigraphic breaks and related sedimentary packages and sea-level cycles.

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اسطح التعرية الكارستيه القديمه في صخور عصر
النيوجين بمنطقة وادى اسل - وادى شرم البحرى
على ساحل البحر الاحمر ، مصر

مرتضى مراد طه العارف
قسم الجيولوجيا - كلية العلوم - جامعة القاهرة

فى المنطقة الواقعة بين وادى اسل - وادى شرم البحرى على
ساحل البحر الاحمر بمصر ثم الاستدلال على تواجد ثلاث اسطح تعرية
كارستيه قديمه فى صخور العصر الثلاثى وهى (1) سطحى تعرية محدودة
الانتشار احداها يوجد بين صخور المايوسين الاوسط التابعة لمكون
ام محرا والاخر يفصل صخور مكون ام محرا عن صخور مكون ابو دياب
ويحتوى على رواسب من معدن السيلستيت و (2) سطح تعرية (كارست)
ذو امتداد اقليمى يؤثر على كل صخور العصر الثلاثى فى المنطقة
والمشتملة على مكونات ام محرا، ابو دياب وام غيج وتتسبب هذه
المرحلة من التجوية الكارستيه فى تشكيل الاشكال الطبوغرافية
الحالية والظاهرة فى منطقة الدراسة او على امتداد ساحل البحر
الاحمر.

تم فى هذا البحث وصف هذه الاسطح تفصيليا وتوضيح نسوع
الرواسب الكارستيه المصاحبة لكل سطح على حدة كذلك التغييرات
المختلفة التى اثرت على الصخور المضيفة - والتعرف على هذه الاسطح
ساعد على الاستدلال على التغير الطبوغرافى لمنطقة الدراسة ومما
صاحبه من انخفاض فى مستوى سطح البحر اثناء وبعد ترسيب السحنات
الرسوبية المختلفة المصاحبة لتصدع البحر الاحمر وأكدت هذه
الدراسة على اهمية اسطح التعرية القديمة لمنطقة البحر الاحمر فى
تجميع رواسب ذات قيمة اقتصادية.